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Title of Research: **"Through the Gas Darkly: An Unobscured X-ray Image of the Milky Way," and "New Starburst Galaxies with Extreme X-ray Luminosities"**

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(NASA-CR-198042) THROUGH THE GAS DARKLY: AN UNOBSCURED X-RAY IMAGE OF THE MILKY WAY AND NEW STARBURST GALAXIES WITH EXTREME X-RAY LUMINOSITIES Annual Status Report, 1 Apr. 1994 - 31 Mar. 1995 (Columbia Univ.) 6 p

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Annual Report for NAG 5-2556

"Through the Gas Darkly: An Unobscured X-ray Image of the Milky Way"

and

"New Starburst Galaxies with Extreme X-ray Luminosities"

My ASCA grant NAG-5-2556 has supported work at Columbia on three main projects: preliminary analysis of a pilot project to assess the feasibility of conducting a Galactic plane survey with *ASCA*, analysis of a Cycle 1 observation of the starburst galaxy NGC 3256, and analysis of the *ASCA* PV target Kes 75, data to which I have access as a consequence of my service on the Science Working Group. Recently, this grant has been amended to cover Cycle 2 observations of the radio pulsar PSR 1929+10, a high redshift ($z = 4.3$) quasar, and another starburst galaxy from the *ROSAT* All Sky Survey; although data from one of these objects has already arrived, I will focus here on the results from the PV and Cycle 1 observations.

Galactic Plane Survey Pilot.

Previous X-ray surveys of the Galactic Plane using non-imaging detectors (e.g., HEAO-1 — Iwan et al. 1982 and *EXOSAT* — Warwick et al. 1985) have revealed bright discrete sources as well as an underlying fainter emission. Away from the Galactic Center, this latter emission component is confined to $|b| \lesssim 1°$ and is referred to as the Galactic "ridge." Partial surveys with the imaging detectors on *Einstein* and *ROSAT* have not been able to determine whether this ridge is the integrated emission from a large population of low-luminosity point sources or is truly diffuse, since the distance one can see into the plane with these soft X-ray telescopes is quite limited. The Ginga spectrum of the emission shows a prominent 6.7 keV iron emission line, characteristic of a hot thermal plasma (Yamauchi and Koyama 1993), although the supernova rate required to sustain such a widespread, hot (3–12 keV) plasma is inconsistent with other estimates by a large factor.

ASCA offers the first opportunity for an imaging survey of the plane at energies above 3 keV. In addition, the high spectral resolution of the ASCA SIS will allow detailed plasma diagnostics of the source (or sources) of this emission. In Cycle 1, we obtained 14 pointings in the region $22.1 < \ell < 24.5$ arranged in three dec strips at $\delta = 0°$ and $\delta = \pm 0.5°$. Only three weak discrete sources appeared in the fourteen 40' fields of view of the GIS. However, bright diffuse emission was present throughout the region. Figure 1 shows the spectrum from the sum of the five fields at $b = 0$ fit to a Raymond-Smith thermal plasma with a temperature of 4.5 keV. The prominent iron line as well as lines near 2 keV due to silicon are apparent. The summed fields at higher and lower latitudes show similar features, although they differ quantitatively in temperature and intensity.

We are now assessing what we can learn about the diffuse emission from these spectra, and reevaluating the plan to conduct a survey characterized by broad sky coverage and

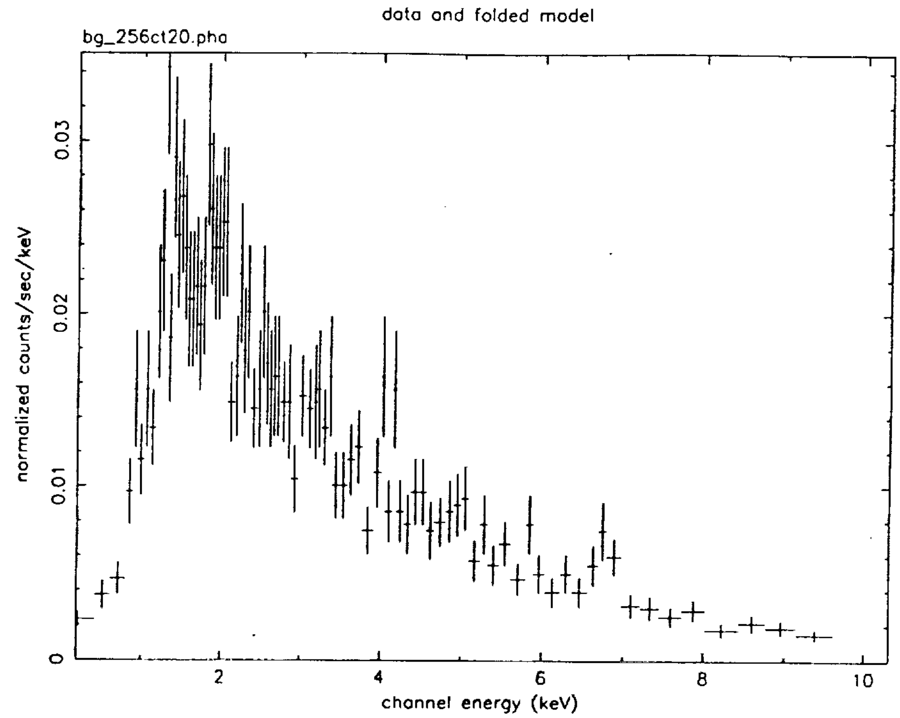

Fig. 1. The GIS spectrum of the diffuse X-ray emission in Galactic plane derived by summing data from 5 fields centered at $b = 0$ and with $22.1 < \ell < 24.5$. Note the prominent silicon and iron lines indicating that the bulk of the emission is from an optically thin plasma with $T \sim 5$ keV.

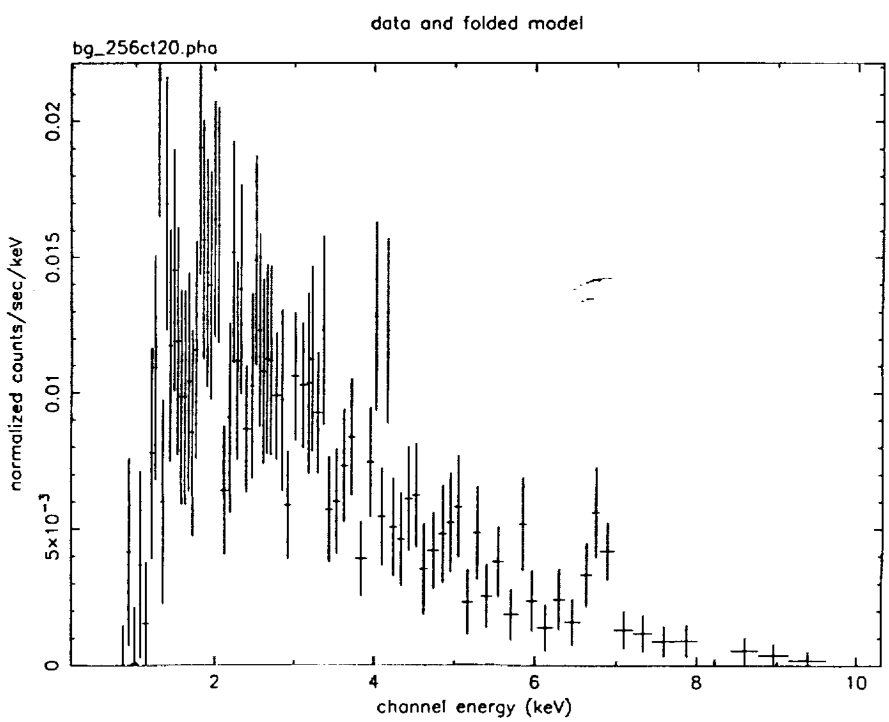

Fig. 2. The difference spectrum of in-plane vs. high latitude backgrounds constructed by subtracting the canonical GIS spectrum from the NGP region from the spectrum at $b = 0$ shown in Fig. 1.

relatively shallow depth; it is possible that deeper exposures over a more limited region may be more useful in determining the origin of this hot plasma which cannot be confined to the plane at these temperatures.

Another important byproduct of this investigation concerns the issue of background subtraction for objects observed near the Galactic plane. Current practice (especially for diffuse sources in which a local background cannot always be obtained) is to use the standard background files obtained from deep pointings at high Galactic latitude. Figure 2 shows the excess of one of the plane fields over the standard background file. It is clear that quantitative results cannot be obtained for Galactic plane sources with the standard processing procedures. Since the diffuse emission is observed to vary in character over scales as small as $30'$, even local background subtraction may be problematic for sources toward the inner Galaxy. We intend to explore variations on even smaller spatial scales by proposing deeper pointings in Cycle 3.

The Composite Supernova Remnant Kes 75.

The canonical model of a Type II supernova predicts a remnant with an expanding shell of hot thermal plasma surrounding a pulsar-driven synchrotron nebula. Although half the remnants in the Galaxy are expected to have Type II progenitors, only a handful of these expected "composite" remnants are known, and in no object younger than 10^4 yr have we been able to demonstrate the existence of spectrally distinct components in the X-ray regime. Our analysis of data obtained during the PV phase for one of the brightest, and youngest, such composite SNRs — Kes 75 — demonstrates dramatically the value of broad-band, moderate resolution imaging spectrophotometry in understanding the progenitors and products of such supernovae.

A draft of a paper describing our results is about to be submitted. Briefly, we find a power-law component confined to the central regions of the remnant with a spectral slope of 1.9, similar to that of the Crab Nebula, as well as a thermal plasma dominated by the helium-like lines of Mg, Si, and S at a temperature of ~ 0.5 keV. The apparent excess of Mg is suggestive of a massive star progenitor in accord with the notion that only in Type II SNe are neutron stars formed. By separating the two components, we can estimate the pulsar's inital and current properties, the mass of thermally emitting material, and the age of the remnant. We conclude that Kes 75 is probably < 1000 yrs old and contains one of the most luminous pulsars in the Galaxy.

The Starburst Galaxy NGC 3256.

The spectacular southern galaxy NGC 3256, with a highly disturbed central region and bright, extended tidal tails, is an excellent example of a merging galaxy system. Due to its extreme brightness in the near infrared and strong narrow emission-line optical spectrum, NGC 3256 has been dubbed a "super starburst" galaxy (Joseph & Wright 1984), undergoing an especially vigorous episode of star formation. The starburst and merger events are expected ultimately to render NGC 3256 a gas-depleted elliptical galaxy (Graham et al. 1984).

NGC 3256 is seemingly a luminous X-ray source as well. The galaxy is among the *IRAS* PSC sources detected in the *ROSAT* All Sky Survey (RASS; Boller et al. 1992). Its soft (0.1–2.4 keV) X-ray luminosity L_X is listed at 2×10^{42} erg s^{-1}, making it the most luminous X-ray starburst galaxy known (*c.f.* Fabbiano 1989). Our followup of 17 objects in the Boller et al. (1992) sample with high X-ray luminosities but optical classifications as normal spiral galaxies or starbursts revealed that most are actually previously unrecognized Seyfert galaxies (Moran et al. 1994); NGC 3256, however, proved to be the only H II galaxy in this group securely identified as an X-ray source. A pointed *ROSAT* PSPC observation, acquired from the archive, confirms that NGC 3256 is a strong X-ray emitter.

NGC 3256 was observed by *ASCA* for $\sim$ 40 ksec on 6 December 1993. The data were edited to remove periods of especially high background, such as those that occur during passages of the satellite through ths South Atlantic Anomaly or when the Earth's limb is at small angular distances from the telescope's optical axis. The total "good time" for observations with the Gas Imaging Spectrometer (GIS) instruments was 40,233s. Due to the comparitively higher background susceptibilty of the Solid-state Imaging Spectrometer (SIS) instruments, just 30,649s of good observation time (in 1-CCD mode) was obtained with them. Hot and flickering pixels were eliminated from the SIS data using the standard cleaning procedure in the XSELECT software. A locally determined background was subtracted from the GIS data. The background level was measured in an annulus (excluding the source) centered on the optical axis with inner and outer radii covering the same range of off-axis angles as the source counts. The GIS background was normalized by the ratio of the source and annulus areas. Background in the SIS images was measured by extracting counts in "blank sky" images, provided by Goddard Space Flight Center, within an aperture identical to the one used to extract the source. The blank sky images were used because the field of view in 1-CCD mode is too small to permit use of a locally determined background. The SIS background was normalized by the ratio of the exposure time in our image to that in the blank sky image. A total of 823 background-subtracted counts were detected in the GIS3 observation.

A principal motivation of this work was to test the hypothesis of Griffiths and Padovani (1992) that such starburst galaxies might have a flat, hard spectrum between 4 and 40 keV (arising in a large X-ray binary population) that could be the long-sought explanation for the flat spectrum of the cosmic X-ray background. It is immediately apparent from the GIS spectrum that no such hard component is present; no photons are detected above background at energies greater than 5 keV; the spectrum can be adequately described by a two component fit including a soft thermal plasma with $kT \sim 0.5$ keV and a slightly hotter thermal bremsstrahlung component with $kT \sim 2$ keV. We interpret the former as arising in supernova remnants and perhaps a SN-driven wind, while the latter is due to a low-mass X-ray binary population typical for a galaxy of this size. A paper describing this work is in draft form and will be submitted to the *Ap.J.* in the next two months.

Personnel and Publications.

In addition to the PI, this grant has been used for the support of two Columbia graduate students, Ms. Elizabeth Blanton and Mr. (now Dr.) Edward Moran. Mr. Moran defended his dissertation in December, one chapter of which consisted of the analysis of NGC 3256; he is now employed as a post doc at IGPP, University of California. Ms. Blanton has pursued the analysis of both the Galactic plane survey data and the supernova remnant Kes 75 as a second-year student research project.

The Kes 75 work was presented at both the High Energy Astrophysics Division meeting at Napa last November, and in a more complete form at the AAS meeting in Tucscon in January; this latter presentation is leading to an article on the work in Sky and Telescope. A next-to-final draft of the paper exists; we expect submission to the Astrophysical Journal within the next two months. The NGC 3256 analysis is complete and the results were included as part of an invited presentation at Napa and as a dissertation talk at the AAS. The writeup of the X-ray analysis is complete, and we are now working to incorporate long-slit optical spectroscopy data for this galaxy which will aid in the interpretation of the soft thermal component in the context of galactic wind models. Again, submission to the *Ap.J.* is expected by May.